**2. Phytoplankton Distributions and Photophysiological States; submitted by Christopher D. Hewes (Legs I & II), John Wieland (Leg I), Rick Reynolds (Leg I), Susana B. Giglio (Leg II), B. Greg Mitchell, Mati Kahru, and Osmund Holm-Hansen (SIO).**

**2.1 Objectives:** The overall objective of our research project was to assess the distribution and concentration of food reservoirs available to the herbivorous zooplankton populations throughout the AMLR study area during the austral summer. Specific objectives of our work was to determine the distribution and biomass of phytoplankton in the upper water column (surface to 200m), with emphasis on the upper 100m, and in conjunction with the NASA SIMBIOS program, (1) to measure pigment-specific absorption by total particulates, detritus and phytoplankton; (2) to measure the spectral attenuation of light with depth; (3) to coordinate these activities with SeaWiFS satellite coverage; (4) to calibrate satellite imagery of spectral reflectance to surface chlorophyll concentrations.

**2.2 Methods and Accomplishments:** The major types of data acquired during these studies, together with an explanation of the methodology employed, are listed below.

**2.2.1 Sampling Strategy:** The CTD carousel and independent profiling units were used to obtain samples of the water column for analyses as well as to obtain data from various profiling sensors as listed below:

(A) For both Legs, water samples were obtained from 10-liter Niskin bottles (with Teflon covered springs) which were closed at 5 meters for every station plus 9 other standard depths (10, 15, 20, 30, 40, 50, 75, 100, and 200m) from every station upcast of the CTD/rosette unit. An exception was made during Leg I when samples for bio-optical measures required larger volumes of water; at these stations, the 15-meter sample was omitted and two Niskin bottles were fired at 5 meters.

(B) For both Legs, two transmissometers (488 and 660nm wavelengths, Wetlabs C-star) were used to determine the attenuation of collimated light (by both scattering and absorption) during CTD casts.

(C) For both Legs, two profiling fluorometers (Wetlabs and SeaTek) were used to measure *in situ* chlorophyll fluorescence.

(D) For Leg I only, a bio-optical instrument package and free-fall profiling reflectance radiometer were deployed at selected CTD stations. These casts were made in conjunction with more detailed analysis of pigment and particulate content from a 5-meter Niskin bottle water sample.

**2.2.2 Measurements and Data Acquired:**

(A) Chlorophyll-*a* concentrations: Chl-*a* concentrations in the water samples were determined by measurement of chl-*a* fluorescence after extraction in an organic solvent. Sample volumes of 100mL were filtered through glass fiber filters (Whatman GF/F, 25mm) at reduced pressure (maximal differential pressure of 1/3$^{rd}$ atmosphere). The filters with the particulate material were placed in 10mL of absolute methanol in 15mL tubes and the photosynthetic pigments allowed to extract at 4°C for at least 12 hours. The samples were then shaken, centrifuged, and the clear supernatant poured into cuvettes (13 x 100mm) for measurement of chl-*a* fluorescence before and after the addition of two drops of 1.0 N HCl. Fluorescence was measured using Turner Designs Fluorometer model #700 having been calibrated using spectrophotometrically determined chl-*a* concentrations of a prepared standard (Sigma). Stability of the fluorometer was verified daily by use of a fluorescence standard.

(B) Miscellaneous optical and cellular measurements: For 31 stations during Leg I, discrete water samples were obtained between 1000 and 1600 GMT (corresponding with the time that SeaWiFS satellite observations of the area became available) for pigment analyses. Water bottle samples obtained at up to three discrete depths were used for each of the following analyses, for which 1-2 liters were filtered through 25mm Whatman GF/F filters:

- ξ Particulate Absorption ($a_p$) and Soluble Absorption ($a_s$). Spectral absorption coefficients of particulate and soluble material were performed on a CARY 100 dual beam spectrophotometer.
- ξ High Pressure Liquid Chromatography (HPLC). HPLC will be used for the analysis of various chlorophylls and associated pigments. Samples were frozen and stored in liquid nitrogen until their analyses can be made at SIO. Chlorophyll and associated pigments will be used to determine the proportions of algal classes contained in the phytoplankton community.
- ξ Particulate Organic Carbon and Nitrogen (POC and PON). Whatman GF/F filters used for sample preparation were combusted at 450°C prior to the cruise. Samples were frozen and will be analyzed by standard gas chromatography methods at the analytical facility at UC Santa Barbara.
- ξ Phycoerythrins (PE). Cryptomonads are a common phytoflagellate in the AMLR study region and are distinguished from other phytoplankton in the area by PE. The filtered water samples were frozen and stored in liquid nitrogen until their analysis at SIO. PE will be measured using a Spex Fluoromax spectrofluorometer.

(C) Several sensors were attached to the SeaBird CTD unit during both Legs I and II for measuring specific characteristics of the water column, and included:

1. Measurement of beam attenuation: Two single wavelength (488 and 660nm) C-star transmissometers (Wetlabs, Inc.) were placed on the Seabird CTD carousel for deployment at each station. Previous studies have shown that beam attenuation (660nm) coefficients can be used to estimate total particulate organic carbon in Antarctic waters (Villafañe *et al.*, 1993). This calculation assumes that there is a negligible load of inorganic sediment in the water, a condition that is apparently satisfied throughout the study area.

2. Measurement of chlorophyll fluorescence: Two profiling fluorometers were used to obtain measures of chlorophyll fluorescence intensity in the water column. These data are used (in conjunction with the measurement of photosynthetically active radiation, PAR) to estimate chlorophyll concentrations *in situ*, using the algorithm of Holm-Hansen *et al.* (2000) as applied specifically for the AMLR survey region.

3. A Biospherical Instruments cosine PAR (photosynthetically available radiation) sensor (Model #QCP-200L) to measure light attenuation profile in the water column. This sensor is also used in conjunction with the SeaTek fluorometer to estimate chlorophyll concentrations *in situ*, and to provide a parameter to measure the variability of photophysiological responses of phytoplankton.

(D) *In situ* optical oceanography: Corresponding approximately in time with the optimal time that the SeaWiFS satellite passed over, a Biospherical Instruments free-fall Profiling Reflectance Radiometer (PRR-800) was deployed. The PRR-800 measured spectral downwelling ($E_d$) and upwelling ($E_u$) irradiances and upwelling radiance ($l_u$) at 19 wavelengths continuously from the surface to the bottom of the profile. Profile depths ranged from 50-200 meters depending on the station. Spectral values of normalized water-leaving radiance will be computed from the PRR-800 data and used to validate SeaWiFS satellite data, as well as, to develop Southern Ocean regional ocean color algorithms.

(E) Seven deployments of an integrated optics package, consisting of a Fast Repetition Rate Fluorometer (FRRF, Chelsea Instruments, Inc.; Kolber *et al.*, 1994) to obtain photophysiological state of phytoplankton communities, and a Hydroscat 6 (HobiLabs, Inc.) to estimate the backscatter of light at 6 wavelengths from 440-700nm.

(F) Satellite Oceanography: SeaWiFS chlorophyll images were obtained for 8-day and monthly average composites from NASA archives (http://eosdata.gsfc.nasa.gov/). These data were sufficient to evaluate the time-dependence and distribution of chl-*a* within our study region.

(G) During the Seal Survey and through the end of Leg I, continuous measures of FRRF were made using the continuous flow system on board (refer to the Physical Oceanography section-Chapter 1 for details). These were complimented with 30 measurements of chlorophyll concentrations during the transect to Punta Arenas, Chile at the end of Leg I.

(H) Two opportunistic stations were made during the transect to Punta Arenas at the end of Leg I (Station BWZ or "blue water" station) and on the return to Cape Shirreff at the beginning of Leg II (Station CWZ). Station BWZ included CTD/PAR/Transmissometer/Fluorometer, PRR-800 and integrated optics package deployment, plus a suite of biological measurements (see items 1 and 2 above) from water samples taken by Niskin bottle. Station CWZ included CTD/PAR/Transmissometer/Fluorometer and chlorophyll measurements from water bottle samples.

(I) During the Near Shore Survey on the southwestern coast of Livingston Island during the beginning of Leg II, measurement of chlorophyll concentrations from the continuous flow system were made at 2-hour intervals.

### 2.3 Tentative Results and Conclusions:

**2.3.1 Overview of phytoplankton distributions in the AMLR survey areas January-March:**
**Leg I** (refer to Figure 2.1A; see also Figure 2 in Introduction section for locations of the different areas and station position in the survey grid):

*West Area*. For the West Area, chlorophyll-*a* at 5m averaged 0.59 ± 0.29 mg $m^{-3}$ (n = 23), and values integrated to 100m were 44 ± 18 mg $m^{-2}$ (n = 25). For this area, chlorophyll concentrations during Leg I were average compared with previous years (5 meter being 0.63 ± 0.99 mg $m^{-3}$ n = 131; 100m integrated being 34 ± 22 mg $m^{-2}$, n = 111). However, notable differences were observed. Stations located in waters less than 1,000 meters depth had concentrations of 0.72 ± 0.21 mg chlorophyll $m^{-3}$ as compared with pelagic stations that had 0.83 ± 0.34 mg chlorophyll $m^{-3}$ (last year coastal stations had much more chlorophyll than pelagic stations). In this regard, of interest is that the highest chlorophyll concentrations for Leg I in the West Area were located off the shelf in deeper waters (Stations A17-07 and A19-09 having > 1.0 milligram $m^{-3}$ in near surface waters). The unusual pattern for chlorophyll distribution in the West Area for Leg I was also reflected in the physical oceanography data (see Physical Oceanography section, this volume). This will be discussed in more detail in section 2.3.3 below.

*Elephant Island Area*: The pattern for surface chlorophyll concentration in the Elephant Island sector followed the bottom topography of the area. Five-meter chlorophyll averaged 0.55 ± 0.28 mg $m^{-3}$, and integrated (100 meters) averaged 44 ± 19 mg $m^{-2}$ for the entire section (42 stations). The shelf and break area around Elephant Island (14 stations) averaged 0.69 ± 0.32 mg chl $m^{-3}$ as compared to 0.49 ± 0.25 mg chl $m^{-3}$ in the oceanic region (22 stations). Chlorophyll concentrations this Leg were average compared with the 12 year Leg I mean (5 meter being 0.79 ± 0.79 mg $m^{-3}$ n = 644; 100m integrated being 43 ± 35 mg $m^{-2}$, n = 591).

*Joinville Island and South Areas*: The pattern for surface chlorophyll concentrations in the Bransfield Strait (South Area) and Joinville Island Area closely follows the zones of water, with low values found for the Weddell Sea (Water Zone V) and high values for the Bransfield Strait (Water Zone IV). Five-meter chlorophyll averages 1.39 ± 0.88 mg $m^{-3}$, and integrated (100 meters) averages 67 ± 21 mg chl $m^{-2}$ for the South Area (14 stations). The Bransfield Strait region closest to the Shetland Islands (7 stations) averaged 1.89 ± 1.00 mg chl $m^{-3}$ as compared to 0.36 ± 0.27 mg chl $m^{-3}$ for those stations closest to the peninsula (10 stations). The most phytoplankton rich area of the entire first Leg were for stations A11-11, A09-09 and A12-12 having highest 5 meter chlorophyll concentrations of 3.2, 2.3 and 2.7 mg $m^{-3}$, respectively. The lowest chlorophyll concentrations of the first Leg were found near the Weddell Sea (Stations A02-13, A04-11, and A04-13), having 0.08 ± 0.01 mg chl $m^{-3}$. For the South Area, chlorophyll concentrations this Leg were above average compared to previous years (5 meter being 1.30 ± 0.89 mg chl $m^{-3}$ n = 63; 100m integrated being 51 ± 34 mg chl $m^{-2}$, n = 45).

**Leg II** (refer to Figures 2.1B and 2.1C):

*Near Shore Survey* (North of Livingston Island, 19-23 February, 2002): During the Near Shore Survey, chlorophyll samples were taken every hour from the continuous flow system (n = 78) in addition to bottle samples obtained during the 21 CTD casts (n = 197). Near surface chlorophyll concentrations ranged 0.14-1.82 mg $m^{-3}$, with waters along the shelf break (500-1,000 meter bottom depth) containing the greatest concentrations (Figure 2.1B). Only Stations C016 and C023 demonstrated chlorophyll maxima at 40-50 meters, while all other stations had generally uniform distributions to the thermocline.

*West Area*: Corresponding with more clear delineation of water zones during Leg II (refer to the physical oceanography section, this volume), chlorophyll at both horizontal and vertical scales approached more classical descriptions (Figure 2.1C; see Holm-Hansen *et al.*, 2000) with notable exceptions. For the West Area, chlorophyll concentrations at 5-meter depths for Water Zone I waters (furthest from the South Shetland and Elephant Islands) averaged 0.44 ± 0.28 mg $m^{-3}$ (8 stations), Water Zone II waters averaged 1.15 ± 0.69 mg $m^{-3}$ (10 stations), and Water Zones III (shelf-related) waters averaged 1.34 ± 0.69 mg $m^{-3}$ (5 stations). Integrated values of chlorophyll (to 100 meters) were 32.3 ± 18.2, 67.7 ± 37.5 and 67.1 ± 25.9 mg $m^{-2}$ for Water Zones I, II, and III respectively. Chlorophyll concentrations for Zone I waters had chlorophyll concentrations that were higher than classically described (generally less than 0.5 mg chl $m^{-3}$ at 5m), and with nearly all stations lacking a chl maxima at and above the thermocline. For Leg II, chlorophyll concentrations for the West Area were 0.96 ± 0.73 mg $m^{-3}$ for 5m samples and 54 ± 30 mg $m^{-2}$ for integrated chlorophyll to 100m. For the roughly the same area, chlorophyll concentrations this Leg were above average compared previous years (5 meter being 0.64 ± 0.72 mg chl $m^{-3}$ n = 94; 100m integrated being 40 ± 36 mg chl $m^{-2}$, n = 78).

*Elephant Island Area*: Five-meter chlorophyll averages for the Elephant Island Area were 0.97 ± 0.57 mg $m^{-3}$, and integrated (100 meters) averages 66 ± 36 mg $m^{-2}$ for the entire Elephant Island Area (43 stations). These surface values are about 80% higher, while integrated values about 50% higher, than those found during Leg I (January). For this area, chlorophyll concentrations for Leg II were about the same as the 12-year average during Leg of 1.08 ± 1.23 mg chl $m^{-3}$ (n = 445) for 5 meters and 61 ± 57 mg chl $m^{-2}$ (n = 504) for 100m integrated values.

*Joinville Island and South Areas*: Phytoplankton biomass decreased over Leg I values for the South Area, with 5m chlorophyll values of 0.95 ± 0.47 mg $m^{-3}$ and integrated values of 52 ± 22 mg chl $m^{-2}$ (n = 25) represented by the South Area, but increased considerably for the Joinville Island area, with 1.06 ± 0.69 mg $m^{-3}$ and 70 ± 29 mg $m^{-2}$ (n = 9) for 5m and integrated (100m) chl, respectively. The South Area phytoplankton biomass for Leg II was considerably less than the 12-year average of 1.93 ± 1.91 mg chl $m^{-3}$ for 5 meters and 110 ± 110 mg $m^{-2}$ for integrated (100m) chlorophyll. Too few data have been collected in the Joinville Island Area to make any comparisons with previous years.

**2.3.2 Opportunistic stations and survey work:** The first opportunistic station (BWZ; 61° 15'S 68° 31'W) was done during the transect back to Punta Arenas at the end of Leg I (Figure 2.2). This station was both preceded and followed up with continuous measurements of phytoplankton biomass and physiology, temperature and salinity from the ship's continuous flow seawater system (Figure 2.3). At Station BWZ, the Antarctic Circumpolar Current had a broad temperature minimum that ranged between 75-160 meters. Although at 160 meters, temperature was -0.27°C and salinity was 34.02‰ to classify it as Water Zone I, this broad and deep range for the temperature minimum was different as compared to previous years. Chlorophyll of 0.29 ± 0.03 mg $m^{-3}$ was distributed to 50 meters with a chlorophyll maximum at 100 meters having 0.55 mg chl $m^{-3}$ (Figure 2.4). A full suite of bio-optical measurements were made at this station.

A second opportunistic station (Station CWZ) was made at 58° 9'S 62° 8'W during transect south to Cape Sherriff at the beginning of Leg II. The temperature profile was more sharp than that found for Station BWZ, however decreasing temperatures began at 37 meters and the temperature minimum occurred at 158 meters with -0.28°C with a salinity of 34.02 ‰ (e.g., also Water Zone I). Chlorophyll concentrations were uniformly distributed with 0.28 ± 0.02 mg chl $m^{-3}$ for the first 50 meters, with no chlorophyll maximum observed.

Continuous monitoring of phytoplankton photophysiology using FRRF connected to the ship's continuous flow seawater system was also done in coastal and shelf regions of the South Shetland and Elephant Islands during the Seal Survey, in addition to that done during the southern excursion through the Gerlache Strait and back to Punta Arenas (Figure 2.2). For the homeward transect, hourly sampling for chlorophyll and high pressure liquid chromatography were obtained from the ship's continuous seawater flow system to 59°S (Figure 2.3A). The highest surface chlorophyll concentrations were measured in the Gerlache Strait (between Anvers Island and the LeMaire Passage) with chlorophyll concentrations reaching 21 mg $m^{-3}$, while the lowest values were found just south of the Polar Front with surface concentrations ranging 0.1-0.2 mg $m^{-3}$.

FRRF data may be interpreted as one indicator of phytoplankton growth rate potential by measuring variable-to-maximal fluorescence (Fv/Fm; Kolber and Falkowski, 1993; Kolber, *et al.*, 1994; Falkowski and Kolber, 1995). Our data from the continuous flow seawater system indicated that Fv/Fm had diel variability as directly related to incident solar radiation (Figure 3.3B), as has been reported (Vassiliev *et al.*, 1994). Although incident photosynthetically active radiation (PAR) accounted for much of this variability, Fv/Fm was secondarily influenced by the Water Zone from where the sample was taken. The Seal Survey mostly occupied shelf and shelf-break waters around King George and Elephant Islands (Figure 2.2), and the most variability in Fv/Fm in relation to PAR for these samples (Figure 2.3B) was found here. Similar large variability in Fv/Fm was found in the Bransfield, Gerlache and Bismark Straits which had amongst the highest near-surface chlorophyll concentrations measured during Leg I (>20 mg $m^{-3}$, Figure 2.3A). In contrast, extremely low chlorophyll containing waters of the ACC (Figures 2.2 & 2.3) demonstrated very little variability of Fv/Fm in relation to PAR. "Coastal" waters during the transect back to Punta Arenas (Figure 2.3B) represented transitional waters (probably Water Zones II and III) encountered between continental shelf and deep pelagic waters (Figure 2.2), and had intermediate concentrations of chlorophyll. The relationship between Fv/Fm and PAR similarly showed a transition between characteristics of high biomass and very low biomass containing waters. The range of values at low PAR for the Straits and coastal waters ranged 0.4 to 0.6, and compares with an upward value of 0.65 for actively growing cells in culture; for ACC and Polar Front waters, Fv/Fm ranged 0.1 to 0.3 at low PAR and compares with those of natural populations having iron limitation (Kolber *et al.*, 1994).

Further comparison between the response of Fv/Fm to PAR for phytoplankton communities in contrasting Water Zones is shown in Figure 2.4. Water column profiles of chlorophyll concentration, temperature, PAR, and Fv/Fm for Water Zones IV (Station A13-13; Figures 2.4A & C) and I (BWZ; Figures 2.4B & D) demonstrate these differences (see Figure 2.2 for locations). Station A13-13 was relatively rich in phytoplankton with >1.0 mg chl $m^{-3}$ near the surface, and decreasing concentrations with depth that followed the pattern of temperature to indicate non-uniform mixing in the upper water column (for practical purposes, e.g. Mitchell and Holm-Hansen, 1991, defining an upper mixed layer, UML, as a change in density > 0.05 kg $m^{-3}$ within 5 meters would indicate that this station did not have one; Figure 2.4A). In contrast, Station BWZ had an UML to 56 meters, but relatively low phytoplankton biomass until the beginning of the thermocline (Figure 2.4B). Both stations had approximately the same PAR at 5 meters (250 ΠEins $m^{-2}$ $s^{-1}$), thus their Fv/Fm can be compared in this respect. For both stations, the Fv/Fm at 100 meters was approximately the same, whereas at the near surface the ratio was considerably higher for Station A13-13 (Figure 2.4C) than for Station BWZ (Figure 2.4D).

To this extent, it has been hypothesized that Water Zone I communities are limited by iron availability (Helbling *et al.*, 1991; Holm-Hansen *et al.*, 1994; Holm-Hansen *et al.*, 2002), and our Fv/Fm data are consistent with those from other high nutrient low chlorophyll waters where iron limited phytoplankton communities have values of ~0.3 (Kolber *et al.*, 1994). Our results from FRRF measurements suggest that the short-term physiological response of phytoplankton to PAR is measurably different for communities in Water Zone I than for other communities located in richer waters near the Antarctic Peninsula, and is consistent with previous results (e.g., Holm-Hansen *et al.*, 2000) that these same communities differ greatly in their non-photochemical quenching of fluorescence relative to chlorophyll concentration relative to PAR.

**2.3.3 Unusual chlorophyll concentrations in Water Zone I:** The horizontal and vertical distributions of chlorophyll were noticeably different during Leg I of the AMLR 2001/02 survey as compared to previous seasons. Satellite images of the horizontal distribution of chlorophyll show that during January, chlorophyll concentrations >1 mg $m^{-3}$ lay extensively beyond the contours defining the 2,000-meter bottom depth north of the South Shetland Islands. In comparison, images from January 2001 (see Hewes *et al.*, 2001), and January 2000 (see Hewes *et al.*, 2000), show chlorophyll distributed near the South Shetland Islands at <2,000 meter bottom, and distributed with respect to the bottom topography. Although the AMLR survey has only extensively surveyed the waters north of Livingston Island since 1996/97, some comparisons can be made (Table 2.1). In general, waters lying well beyond the shelf break region (depths >2,000m) north of the South Shetland Islands have historically been classified as Water Zone I (see Physical Oceanography sections from AMLR Field Season Reports 1996/97 through 2000/01). For waters in the northwest sector of the West Area (61.5-62.0°S X 61.5-62.0°W), 5-meter chlorophyll measured during Leg I was 0.09± 0.03 mg $m^{-3}$ (1996/97 – 2000/01, not done in 1999/00). In comparison, the same area measured 0.86 ± 0.21 during 2001/02. The 5-meter water temperature in this section was also colder than in previous years. During Leg II, water temperatures warmed up to almost the average for preceding years (Table 2.1). However, chlorophyll concentrations *diminished* to levels slightly above those from the preceding years, and are in contrast to a trend that phytoplankton biomass remains the same or slightly increases during Leg II. The same general conclusions can be made with regard to temperature and phytoplankton biomass in the northeast sector of the West Area (61.0S-61.5°S X 60.5S-61.0°W; Table 2.1), that cooler water temperatures and higher than average phytoplankton persisted during Leg I, and approached normal levels during the course of Leg II. This is born out by the SeaWiFS chlorophyll images for the general Drakes Passage/Scotia Sea region for January through March monthly composites (Figure 2.5).

That chlorophyll decreased during Leg II could be due to the much later time of the season that samples were obtained as compared to previous years. Evidence for this is found with the monthly composite image of chlorophyll distribution during February (Figure 2.5). A bloom developed south of King George Island in the Bransfield Strait while we were in transit between

Legs I and II as well as during the Near Shore Survey. This bloom persisted for the weeks ending February 9 and February 17 as indicated by 8-day composites of chlorophyll distributions (Figure 2.6). Of further note was the development and persistence of an eddy-like bloom just north of the Elephant Island Area along the Shackleton Fracture Zone. Eight-day composites (Figure 2.6) show the beginning of bloom formation around the week of January 16, maximizing its extent through the month of February, and decaying sometime in March (clouds obstructed further observation after March 13). The central portions of this bloom provided some of the highest concentrations of chlorophyll (red spots in the image for March 13) for the entire northern Peninsular region (also see Figure 2.5).

Regardless of the fact that during Leg I surface water temperatures were below normal for the AMLR Survey Areas mentioned above (Table 2.1), water column profiles indicated that Water Zone I was in evidence (Figure 2.7A). For Station 19-09 (located in the northwestern section of the West Area, Table 2.1), temperature/salinity plots classify this station as Water Zone I, with temperature minimums occurring at 50-100 meter depth. For Station 15-05 (located in the northeastern section of the West Area, Table 2.1), temperature/salinity plots classify this station as Water Zone I during Leg II, but borderline Water Zones I-II during Leg I. Holm-Hansen *et al.* (1997) distinguished two classes of Water Zone I as based on both nutrient concentration and the horizontal chlorophyll distribution. Water Zone IA waters were of very low chlorophyll concentrations ($<<0.4$ mg $m^{-3}$) distributed in the UML, with a small chlorophyll maximum that lay just below the beginning of the thermocline (see Figure 2.4B). Water Zone IB waters resembled Water Zone IA waters in the physical sense by having a distinct temperature minimum, but chlorophyll concentrations were two-to-three times higher (0.3-0.6 mg $m^{-3}$) in the UML and no chlorophyll maximum present. For both Legs, few stations met the biological criteria of being Water Zones 1A for the 2001/02 field season survey. Holm-Hansen *et al.* (1997) suggested that the higher biomass in Water Zone IB waters could be the result of a lateral advection from coastal surface waters, since these contained similar macro nutrient concentrations, shoaled on top of the Winter Water layer, which provided the temperature minimum characteristics of Water Zone I. Yet, even with satellite images of the surface chlorophyll distributions for the general region encompassing the AMLR survey region (Figures 2.5 & 2.6), it is difficult to assess what mesoscale processes were dominating the physical environment to provide conditions of elevated phytoplankton biomass in such normally oligotrophic pelagic waters. Although Station 15-05 developed into a Water Zone IA - like situation with regard to the physical structure and chlorophyll concentration of the water column during Leg II (Figure 2.7B), chlorophyll concentrations remained well above those that have been considered normal for Water Zone IB waters.

**2.4 Disposition of the Data:** All chlorophyll and CTD-interfaced sensor data obtained during these cruises have been archived with AERD, Southwest Fisheries Science Center. Data from all other measurements listed in 2.2.2 will be processed by Dr. B.G. Mitchell under his NASA SIMBIOS project.

**2.5 Problems and Suggestions:** It should be noted that the phytoplankton component of the AMLR program has not obtained funds for the calibration, repair, or replacement of field equipment (both laboratory equipment and *in situ* sensors) used in these annual surveys. Many of our instruments devoted to this program (originally obtained from other funding agencies) for the past 13 years began to fail the past few years, and the situation has become critical. Additional NOAA funding should be made available to maintain and/or replace such instruments, since the scope and quality of our data for future AMLR field years will be compromised.

**2.6 Acknowledgements:** We want to express our gratitude and appreciation to the entire complement of the R/V *Yuzhmorgeologiya* for their generous and valuable help during the entire cruise. They not only aided immeasurably in our ability to obtain the desired oceanographic data, but they also made the cruise most enjoyable and rewarding in many ways. We also thank all other AMLR personnel for help and support which was essential to the success of our program. This report has been funded in part to O. Holm-Hansen from the National Oceanic and Atmospheric Administration, U.S. Department of Commerce, under grant NA17RJ1231, and by a NASA SIMBIOS Project Award to B. Greg Mitchell, NAS5-01002. The views expressed herein are those of the authors and do not necessarily reflect the views of NOAA or any of its sub-agencies.

**2.7 References:**

Helbling, E.W., Villafane, V.E., and Holm-Hansen, O. 1991. Effect of Fe on Productivity and Size Distribution of Antarctic Phytoplankton. *Limnology and Oceanography* 36: 1879-1885.

Hewes, C.D., Wieland, J., Mitchell, B.G., Kahru, M., and Holm-Hansen, O. 2001. Phytoplankton and Optical Oceanography. Pages 37-50 in (Jessica Lipsky, *ed.*) AMLR 2000/2001 Field Season Report Objectives, Accomplishments and Tentative Conclusions. September 2001. NOAA-TM-NMFS-SWFSC-314. http://swfsc.ucsd.edu/aerg/FLDSEA_RPT/AMLR00_01/Chapter2.pdf

Hewes, C. D., Hewitt, R.P., Mitchell, B.G., and Holm-Hansen, O. 2001. Phytoplankton. Pages 26-36 in (Jessica Lipsky, *ed.*) AMLR 1999/2000 Field Season Report Objectives, Accomplishments and Tentative Conclusions. March 2001. NOAA-TM-NMFS-SWFSC-32. http://swfsc.ucsd.edu/aerg/FLDSEA_RPT/AMLR99_00/2.pdf

Holm-Hansen, O., Amos, A.F., Silva S, N., Villafañe, V.E., and Helbling, E.W. 1994. *In situ* evidence for a nutrient limitation of phytoplankton growth in pelagic Antarctic waters. *Antarctic Science* 6: 315-324.

Holm-Hansen, O., Hewes, C.D., Helbling, E.W., Villafañe, V.E., and Amos, A.F. 1997. Phytoplankton biomass and distribution in relation to water masses around Elephant Island, Antarctica. *Polar Biology* 18: 145-153.

Holm-Hansen, O., Amos, A.F., and Hewes, C.D. 2000. Reliability of estimating chlorophyll-a concentrations in Antarctic waters by measurement of in situ chlorophyll-a fluorescence. *Marine Ecology Progress Series* 196: 103-110.

Holm-Hansen, O., Kahru, M., Hewes, C.D., Kawaguchi, S., Kameda, T., Sushin, V.A., Krasovski, I., Priddle, J., Korb, R., Hewitt, R.P., and Mitchell, B.G. 2002. Distribution of chlorophyll-a in surface waters of the Scotia Sea as determined by both shipboard measurements and from satellite data. Submitted to *Deep-Sea Research*.

Falkowski, P., and Kolber, Z. 1995. Variations in chlorophyll fluorescence yields in phytoplankton in the world oceans. *Australian Journal of Plant Physiology* 22: 341-355.

Kolber, Z., and Falkowski, P. 1993. Use of active fluorescence to estimate phytoplankton photosynthesis in situ. *Limnology and Oceanography* 38: 1646-1665.

Kolber, Z., Barber, R., Coale, K., Fitzwater, S., Greene, R., Johnson, K., Lindley, S., and Falkowski, P. 1994. Iron limitation of phytoplankton photosynthesis in the equatorial Pacific Ocean. *Nature* 371: 145-149.

Mitchell, B.G. and Holm-Hansen, O. 1991. Bio-optical properties of Antarctic Peninsula waters: differentiation from temperate ocean models. *Deep-Sea Research I* 38(8/9): 1009-1028.

Vassiliev, I., Prasil, O., Wyman, K., Kolber, Z., Hanson, Jr. A., Prentice, J., and Falkowski, P. 1994. Inhibition of PS II photochemistry by PAR and UV radiation in natural phytoplankton communities. *Photosynthesis Research* 42: 51-64.

Table 2.1. Comparison of AMLR 2001/02 chlorophyll concentrations and temperature with those of previous years for two regions in the West Area. Leg I chlorophyll was much higher and surface water temperature much cooler than the average from previous surveys. Leg II also deviated from "normal", but was not as extreme as Leg I. Also see Figure 2.7.

| Area | Year(s) | | Leg I | | | | Leg II | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | N = | Temp., °C | 5 m Chl, mg $m^{-3}$ | Integr. Chl, mg $m^{-2}$ | N = | Temp., °C | 5 m Chl, mg $m^{-3}$ | Integr. Chl, mg $m^{-2}$ |
| 61.5 - 62.0 °S X 61.5 - 62.0 °W | 1997 - 2001 | average | 11 | 2.09 | 0.09 | 14.73 | 8 | 2.45 | 0.18 | 14.94 |
| | | stdev | | 0.54 | 0.03 | 9.19 | | 0.41 | 0.20 | 11.15 |
| | 2002 | average | 3 | 1.36 | 0.86 | 67.19 | 3 | 2.23 | 0.55 | 47.76 |
| | | stdev | | 0.28 | 0.21 | 17.05 | | 0.32 | 0.30 | 22.98 |
| 61.0 - 61.5 °S X 60.5 - 61.0 °W | 1997 - 2001 | average | 11 | 2.41 | 0.15 | 11.49 | 7 | 2.59 | 0.16 | 30.43 |
| | | stdev | | 0.47 | 0.16 | 11.61 | | 0.71 | 0.28 | 15.81 |
| | 2002 | average | 3 | 1.28 | 0.59 | 43.90 | 4 | 2.38 | 0.38 | 33.17 |
| | | stdev | | 0.22 | 0.33 | 20.15 | | 0.20 | 0.23 | 20.89 |

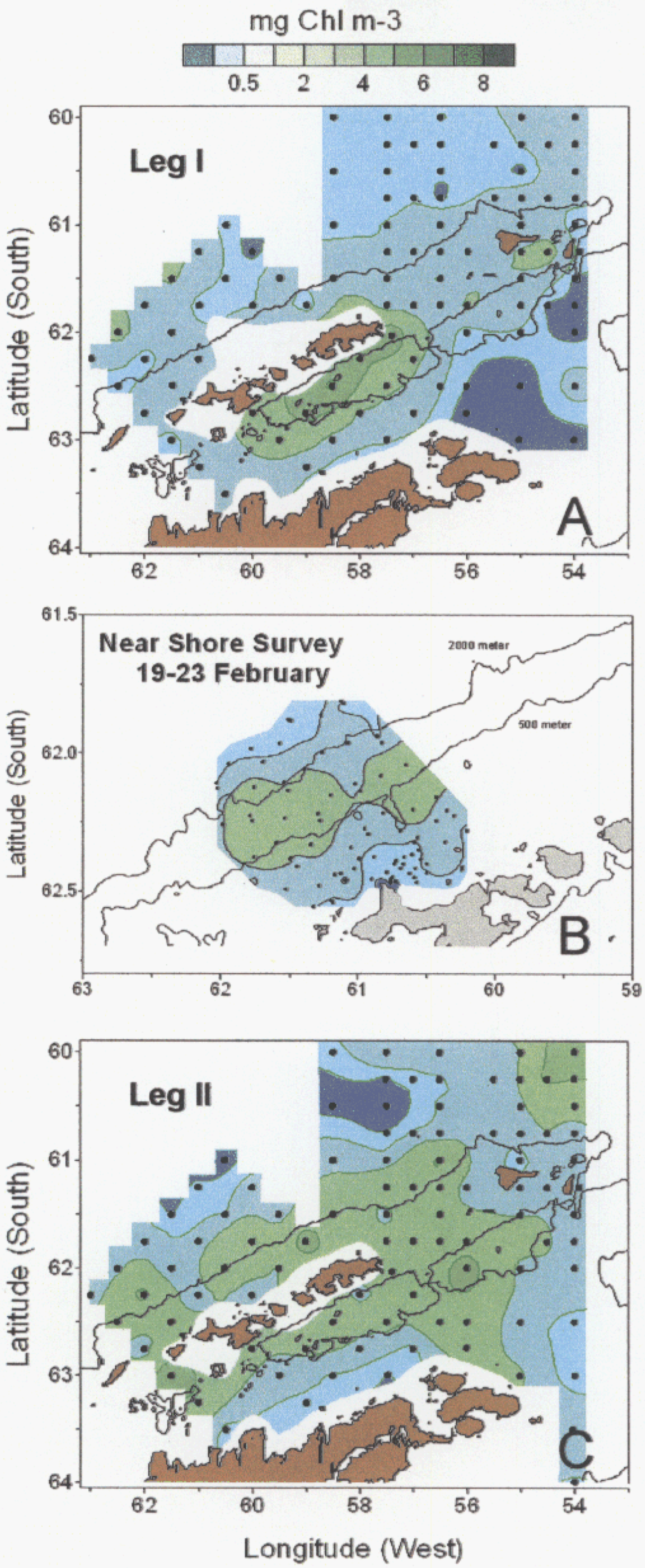


Figure 2.1. Distributions of near surface chlorophyll concentrations during (A) Leg I, (B) the near shore survey, and (C) Leg II. The 2000 meter bottom contour line is shown in A and B, while both 500 and 2000 meter bottom contour lines are shown in C. Filled circles represent locations that bottle samples were made. For A and C, 5 meter bottle data (10 meter if missing 5 meter) plotted. For the near shore survey, B, concentrations plotted were from the continuous flow seawater system (~7 meter depth) sampled every two hours.

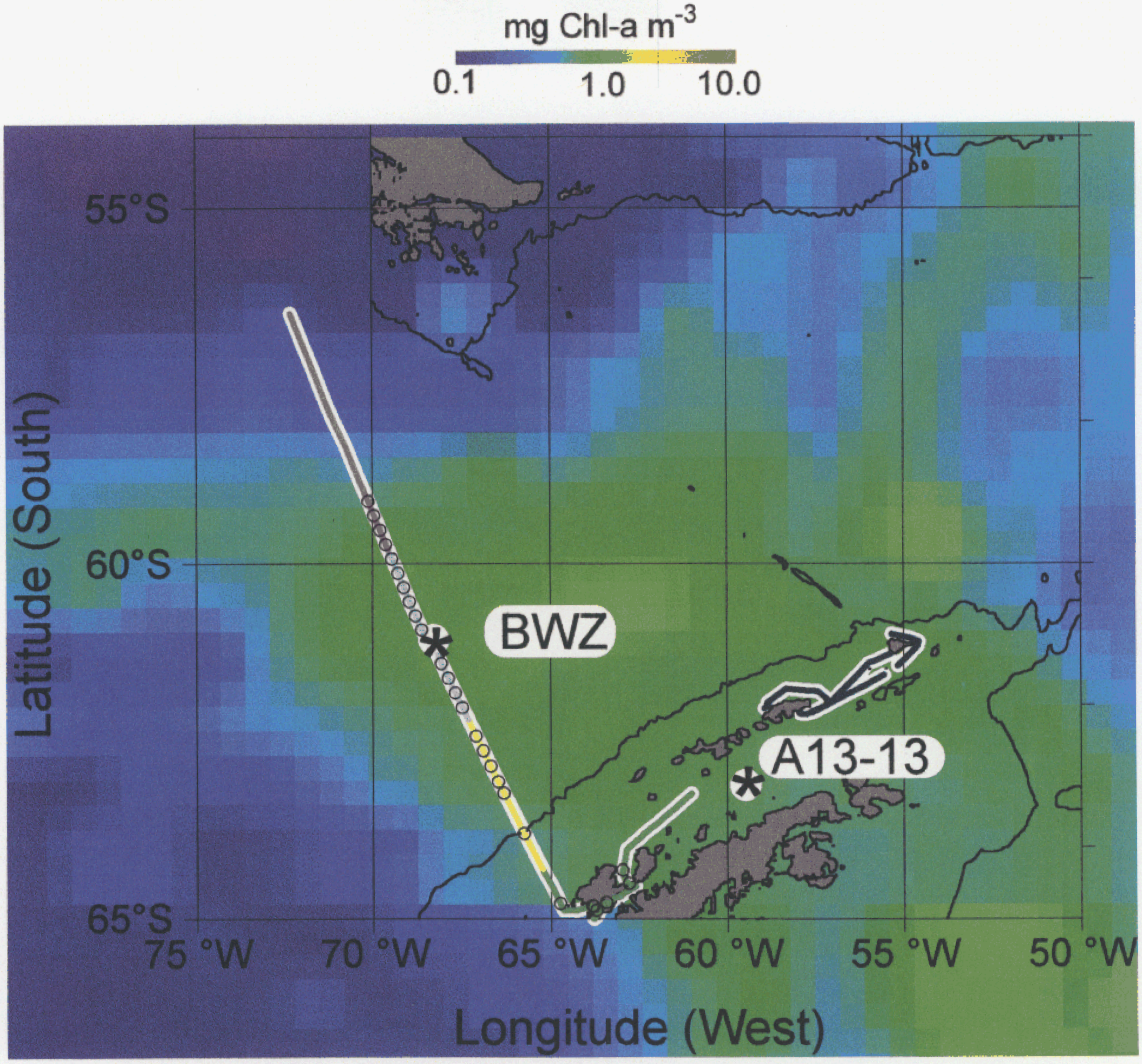


Figure 2.2. Cruise track of the underway sampling where FRRF was attached to the continuous flow seawater system overlaying chlorophyll distribution for monthly composite for February, 2002, as measured by SeaWiFS satellite (see text for details). Symbols are the locations where chlorophyll and HPLC samples were taken. Colors of the cruise track lines refer to areas described in Figures 3 and 4, corresponding with: Black, Seal Survey; Green, Straits; Yellow, Coastal; Light Blue, ACC; Violet, Polar Front. The 2,000 meter bottom contour drawn as the thin light black line. The locations of Stations A13-13 and BWZ are shown.

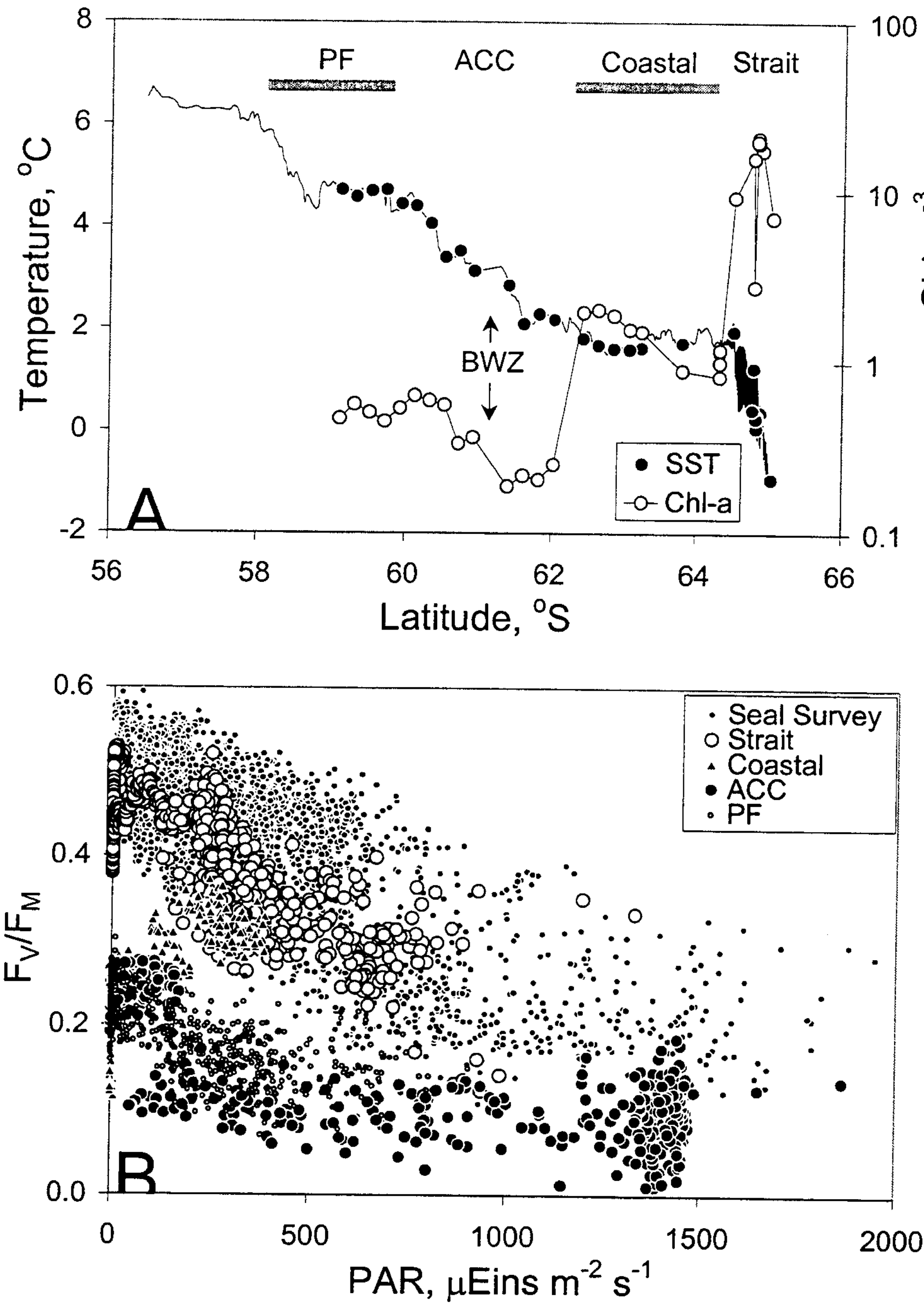


Figure 2.3. A) Chlorophyll concentration and temperature measured at locations shown in Figure 2 during the return to Punta Arenas at the end of Leg I. Four areas, Strait (Bransfield, Gerlache, and Bizmark Straits), Coastal, Antarctic Circumpolar Current (ACC), and Polar Front (PF) were based on chlorophyll concentration and temperature. B) Fv/Fm (measured by FRRF hooked up to the continuous flow seawater system) plotted against ambient PAR. The areas described in A are compared to those values measured during the Fur Seal Pup Survey.

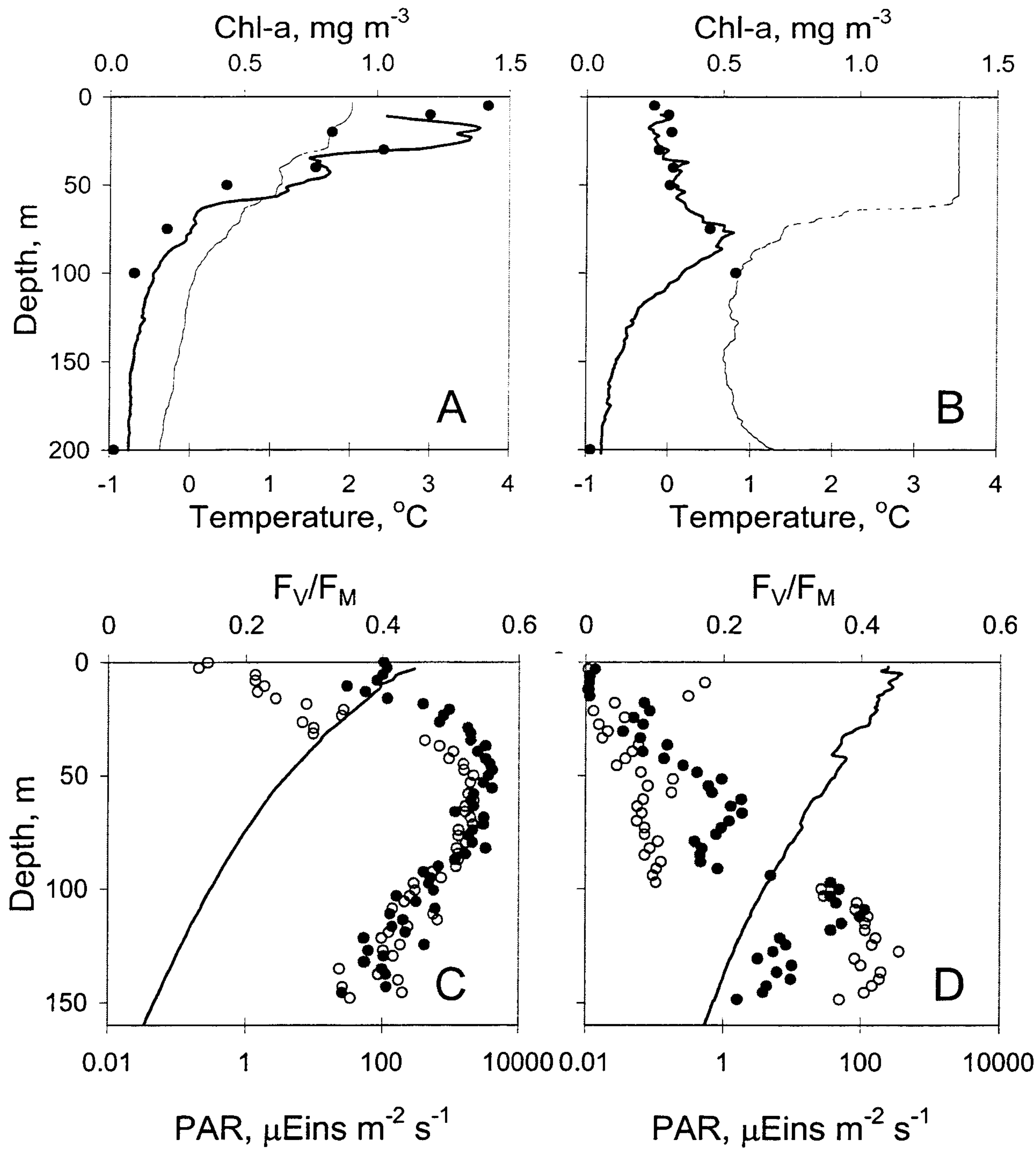


Figure 2.4. Comparison of vertical profiles for (A and B) temperature (thin lines), chlorophyll (filled circles) and chlorophyll estimated from in situ fluorescence and PAR (Holm-Hansen *et al.*, 2000; heavy lines), and (C and D) PAR (heavy lines) and Fv/Fm (measured in the dark, filled circles, and in the light, open circles) between Station A13-13 (Bransfield Strait, A and C) and Station BWZ (B and D).

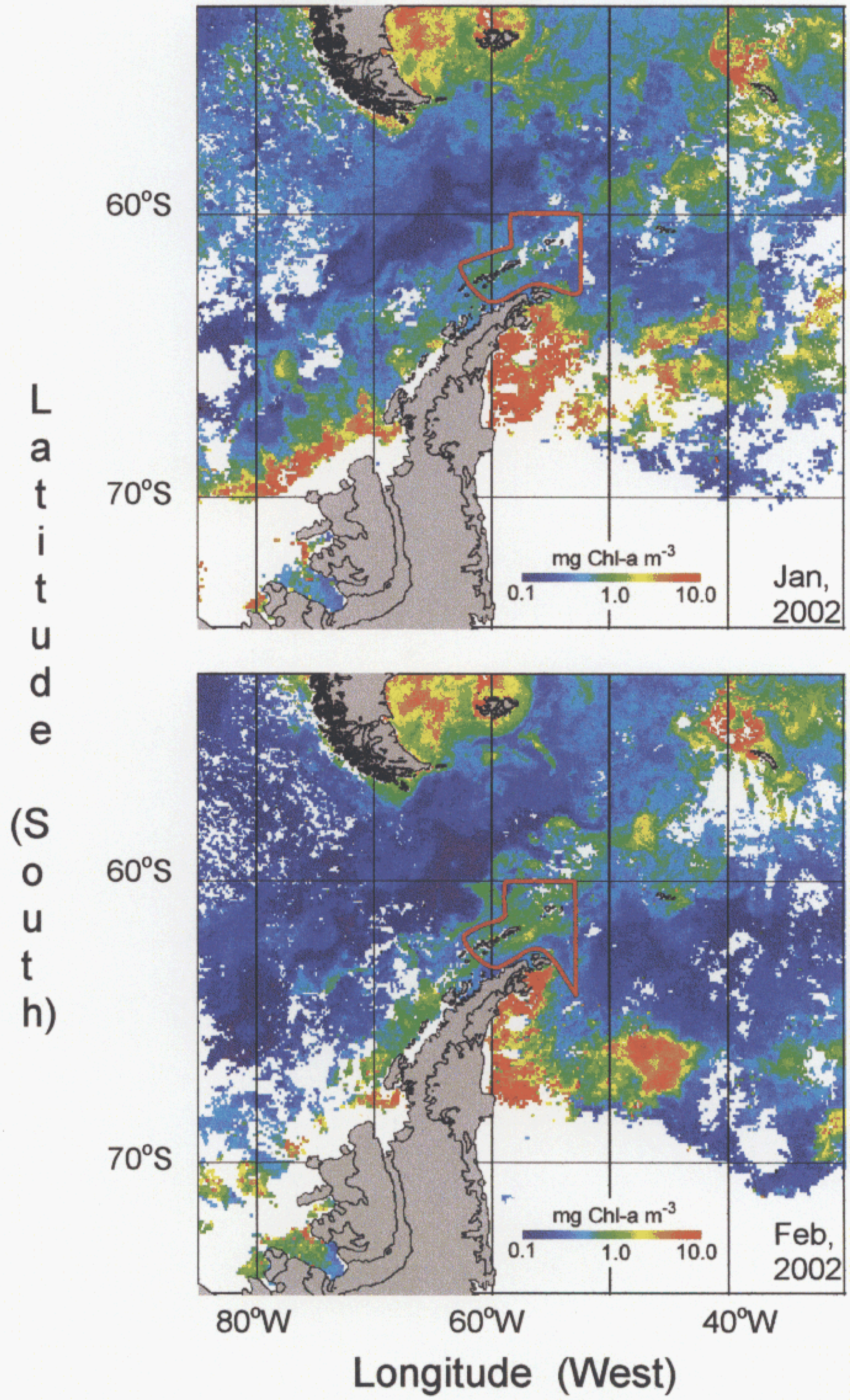


Figure 2.5. Monthly composites for SeaWiFS satellite derived chlorophyll distributions for January and February, 2002 in the regions surrounding the AMLR survey area (enclosed red areas) during Legs I and II. Note both (1) the strengthening of the low chlorophyll containing region (deep blue) between South America and the Antarctic Peninsula and (2) intensification of phytoplankton blooming (green and yellow) around the Shetland / Elephant Islands region and northeastward towards South Georgia. White areas represent persistent ice and cloud cover.

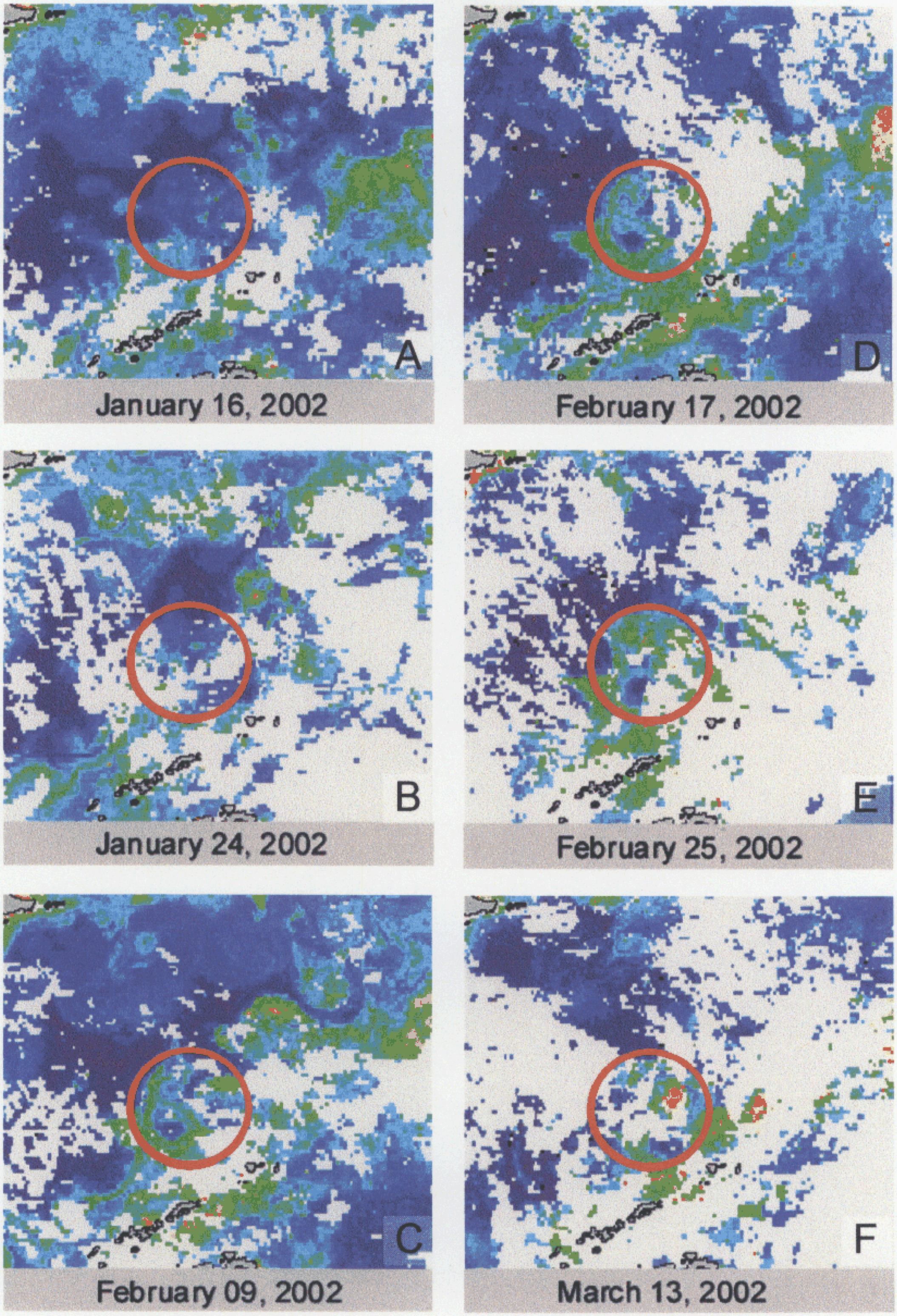


Figure 2.6. Eight-day composites of SeaWiFS satellite chlorophyll distributions showing development and persistence of an off-shelf phytoplankton bloom (red circle) during the AMLR 2001/02 field survey. Refer to Figure 5 for color scale and relative locations (red circle centered at approximately 59°S 58°W). Light grey represents cloud cover.

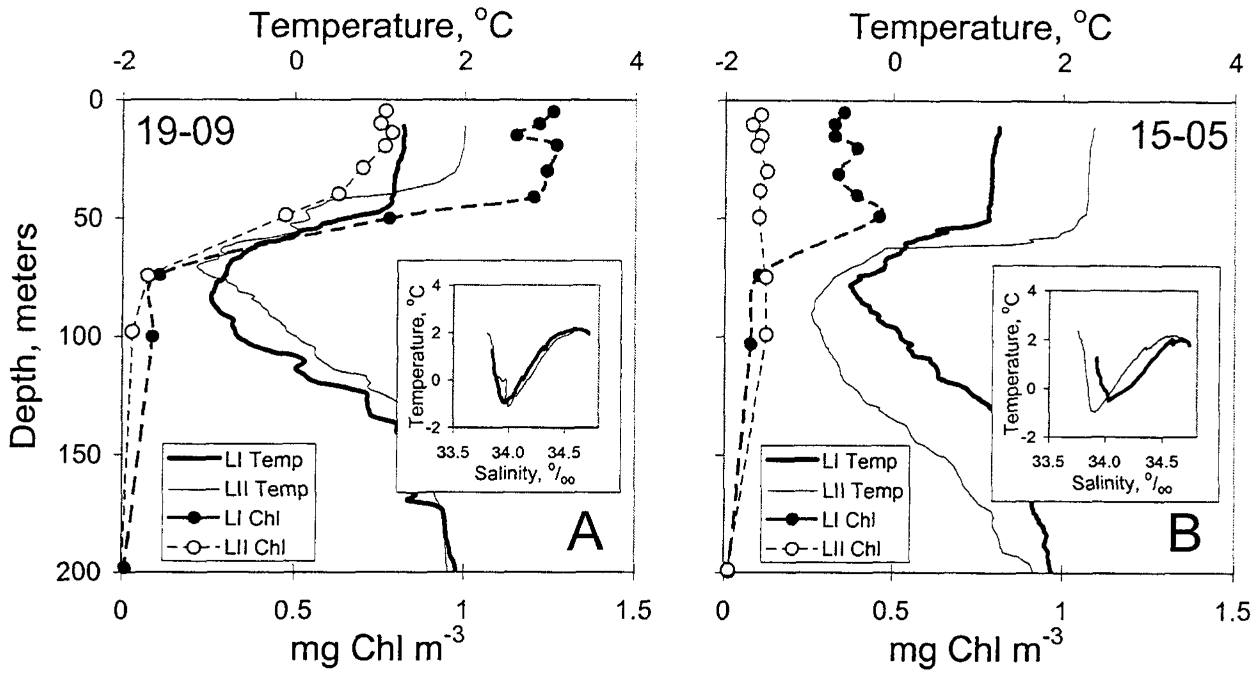


Figure 2.7. Vertical distributions of chlorophyll (circles) and temperature (solid lines) for stations 19-09 (A) and 15-05 (B) (northwest and northeast corners of the West Area, also see Table I) to compare Legs I (heavy lines) and II (light lines). Inserts show the relationship of temperature verses salinity. Water Zone I is characterized by a temperature minimum having a salinity <34.0 $^{o}/_{oo}$, for which all were except for Station 15-05 (B) Leg I which was Water Zone II. Typically Water Zone I may be characterized (e.g., Holm-Hansen *et al.*, 1997) as IA, having low chlorophyll concentrations (<0.2 mg $m^{-3}$) between the surface and thermocline and a chlorophyll maximum (<0.5 mg $m^{-3}$) just below the thermocline, or IB, having uniformly distributed chlorophyll (0.3-0.6 mg $m^{-3}$) to the thermocline. Station 15-05 during Leg II (B) was the only "typical" IA condition, with the others shown as having much higher concentrations of chlorophyll than usually considered for IB waters.